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ILLUSTRATION OF YEAR-TO-YEAR VARIATION IN WHEAT SPECTRAL PROFILE CROP GROWTH CURVES

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ILLUSTRATION OF YEAR-TO-YEAR VARIATION IN WHEAT SPECTRAL PROFILE CROP GROWTH CURVES

PREPARED BY:

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EARTH OBSERVATIONS DIVISION
AUGUST 1980

Illustration of Year-to-Year Variation
in Wheat Spectral Profile Crop
Growth Curves

I. OBJECTIVE:

The purpose of this publication is to illustrate data compiled by the University of California at Berkeley in a study of twelve spring and winter wheat segments in the Dakotas, Kansas, and Oklahoma.[1]

II. BACKGROUND:

A. The UCB Study

The study concerns itself with variations in temporal-spectral characteristics for a given crop. The primary objective was to measure and quantitatively describe the year-to-year variation in crop temporal-spectral response patterns due to any year-to-year variation in the physical environment.

In order to determine the yearly variation in crop temporal-spectral response, it was necessary to develop a measuring system which is acquisition independent. One way this can be accomplished is by estimating a continuous spectral response curve for a crop as a function of time. From such a curve, one can determine major spectral events (spectral biostages) for a crop (e.g. maximum amplitude of a vegetation indicator, date of first green canopy detection) and assess the year-to-year variation in such events. The function used to generate the continuous temporal plot is

$$F = T^{B1} e^{B2\,T^2 + B3}$$

Where F = the value of the green vegetation indicator (GRABS), T = day of the year, and B1, B2, B3 are coefficients estimated by a least squares procedure. This particular function was chosen for its appropriate shape and its adaptability by logarithmic transformation to estimation by least squares linear regression. However, estimation by least squares linear regression proved to be unsatisfactory because there is no obvious variance term to associate with a temporal-spectral value derived from such a segment-average curve.

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1. Hay, C.M., et. al., <u>Annual Progress Report</u>, Space Sciences Laboratory, University of California (Berkeley), November 1979.

In addition, the curve fit is extremely poor in some cases. For these reasons a nonlinear least squares program was developed to estimate the coefficients of the function. For each wheat field, the following variables were calculated from the equations generated by the nonlinear curve-fitting program.

F_{max} = maximum GRABS value
T_{max} = day of maximum GRABS
T_b = day of first detectability
T_a = day of harvest

The corresponding average values for each segment-year were calculated by taking the unweighted arithmetic mean over all sampled fields within that segment-year. These values are represented by the curves in the accompanying graphs.

B. The Data

The data set was prepared from Landsat MSS data and the segments were selected on the basis of: 1) the number of years of Landsat and ground truth data available, 2) adequate within-year acquisition histories, 3) diversity in number of drought stress years, and 4) geographical diversity. The MSS data was sun angle and haze corrected, and a green vegetation indicator was calculated for each pixel. Wheat fields in specific segment-year combinations were then randomly sampled.

Ground truth data was available for all the segments in years '77 and '78, but of the segments plotted only 1851 had ground truth in '76. For those segment-years in which ground truth was not available, the wheat fields were identified by analyst interpretation.

III. CALCULATION OF CURVES

The curves illustrated in the graphs were derived using a procedure common to the entire data set. The data consists of twenty three sets of the following variables.

T1 = date of first detectability
F1 = GRABS threshold for detectability (=2)
T2 = date of peak GRABS
F2 = peak GRABS

T3 = date of harvest

F3 = F1 (=2)

These variables are essentially x and y coordinates for three points on a curve. Using these values for T (day of year) and F (GRABS) along with the function

$$F = T^{B1} e^{B2\,T^2 + B3}$$

one can solve for a system of three equations and three unknowns using gaussian elimination.

General Form: Ax = b

$$\ln(T1)*B1 + (T1)^2*B2 + B3 = \ln(F1)$$
$$\ln(T2)*B1 + (T2)^2*B2 + B3 = \ln(F2)$$
$$\ln(T3)*B1 + (T3)^2*B2 + B3 = \ln(F3)$$

Example: For segment 1175, year '76 (see Table 1.2), the following were mean values over 15 fields:

T1=40.87 T2=95.55 T3=165.36 F1=2.00 F2=18.00 F3=2.00

The System to be solved is:

3.71040*B1 + 1670.35681*B2 + 1.00000*B3 = 0.69315

4.55965*B1 + 9129.80273*B2 + 1.00000*B3 = 2.89037

5.10812*B1 + 27343.92969*B2 + 1.00000*B3 = 0.69315

The Solution Vector is:

B1 = 4.95862 B2 = -0.00027 B3 = -17.25308

An arbitrary number of values for F can now be generated for arbitrary values of T.

$$F_i = T_i^{B1} e^{B2\,T_i^2 + B3} \quad , i=1,30$$

Plotting F_i versus T_i yields the desired curve for this particular set of T1, T2, T3, F1, F2, F3. This procedure can similarly be extended to plot the remaining data. It should be noted that the curves represent mean values for the fields within a given segment-year. Judging from the standard deviations (see Table 1.2) of the parameters, a profile curve for an individual field within a segment-year will likely vary considerably from the mean profile curve for that segment-year.

IV. CONCLUSIONS:

UCB concluded that the curves show no significant correlation between the spectral variable F_{max} and any of the temporal variables. This result denies support to ideas asserting that the relative earliness or lateness of a crop's development affects the value of its spectral peak. However, significant correlations were observed between T_{max} and T_b and between T_{max} and T_a. Alternatively, the relative earliness (or lateness) of the GRABS peak was associated with the relative earliness (or lateness) of both first detectability and harvest.

Another observation made by UCB contends that within any segment, the year-to-year variation of crop growth characteristics were generally more significant than was the field-to-field variation within the same year. In addition, the nature and magnitude of the field-to-field variability was found to be constant in two thirds of the cases studied.

Figure 1.1

Location of Study Segments

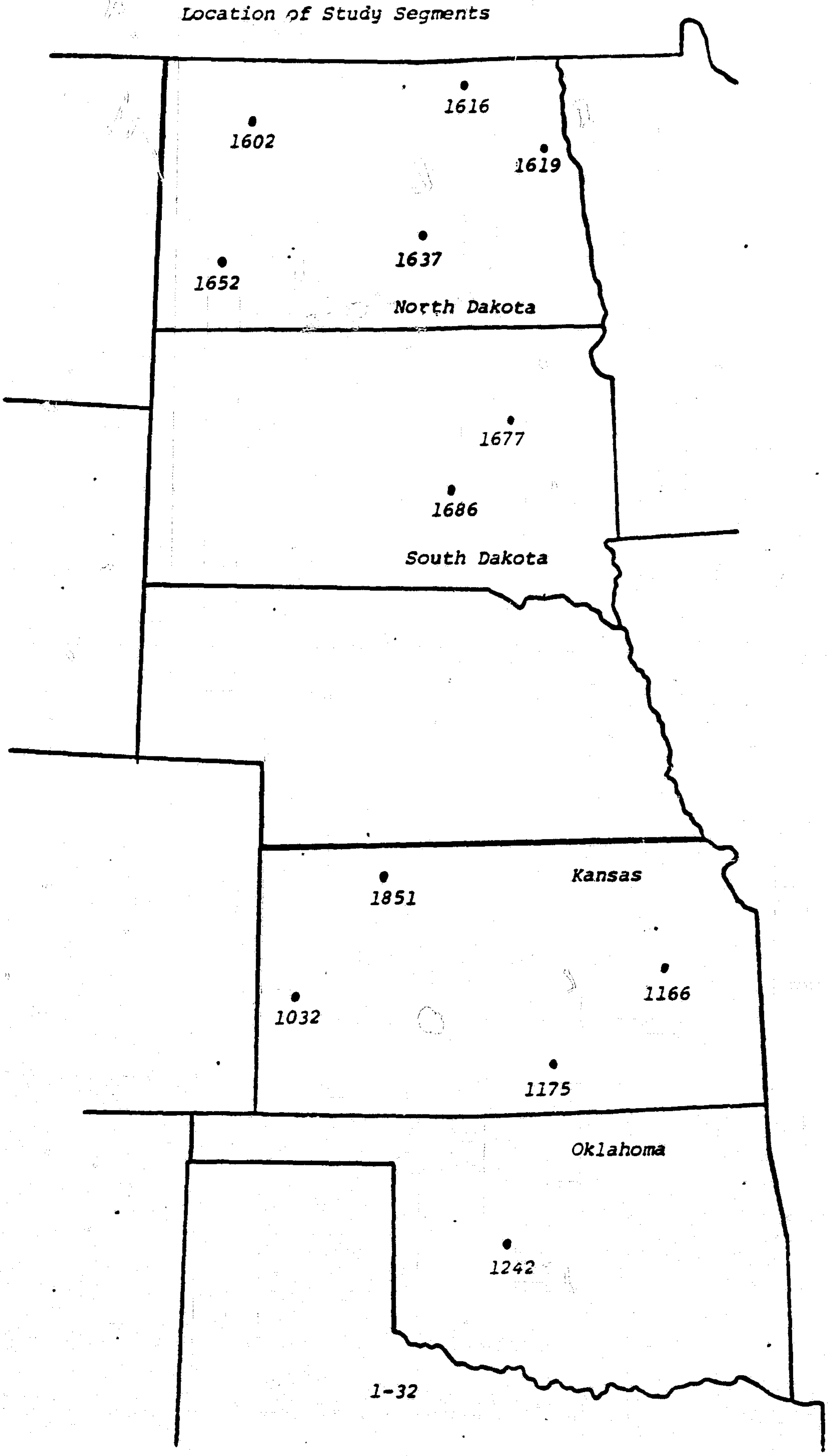


Table 1.2

Segment-Year Average Temporal-Spectral Variables

		F_{max} mean	F_{max} std. dev.	T_{max} mean	T_{max} std. dev.	Number of fields
Spring Wheat						
1602	75	17.42	10.95	194.74	3.48	7
	76	22.29	4.27	190.06	4.31	13
	77	27.12	5.16	181.71	5.20	18
1616	75	36.62	7.79	195.59	3.87	15
	76	19.15	3.80	185.04	5.95	13
	77	45.41	10.69	179.88	2.79	11
1619	76	23.18	5.59	172.57	7.31	15
	77	12.43	6.87	196.83	13.34	5
	78	20.87	6.56	190.62	8.79	13
1637	75	27.42	4.67	196.51	8.47	13
	76	20.67	5.10	181.00	5.63	12
	77	31.43	8.32	179.85	7.64	14
	78	25.50	7.79	195.93	9.72	9
1652	76	[illegible]	13.42	178.02	5.62	13
	77	12.98	8.09	180.09	5.79	20
1677	75	21.54	6.53	165.29	6.85	15
	76	5.71	2.53	159.83	6.51	7
	77	22.00	7.21	165.68	8.10	14
	78	18.39	6.81	193.50	6.52	7
1686	75	19.20	8.11	161.74	14.44	8
	76	10.56	3.14	165.29	2.93	4
	77	6.22	2.97	163.95	9.25	11
	78	10.54	6.95	200.16	8.54	13
Mean		21.03		181.47		
Winter Wheat						
1175	76	18.00	4.21	95.55	7.40	9
	77	22.75	5.62	93.32	3.74	9
	78	28.94	7.09	119.63	2.58	15
1851	76	20.24	5.25	126.00	4.88	13
	77	23.22	8.38	129.36	3.74	14
1242	76	15.58	5.49	55.58	10.16	15
	77	23.02	12.77	70.17	17.92	8
Mean		21.68		98.52		

F_{max} = maximum GRABS value

T_{max} = Julian date of maximum GRABS

Table 1.2 Continued

Segment-Year Average Temporal-Spectral Variables

		T_b		T_a		$T_{max} - T_b$		$T_a - T_b$	
		mean	std.dev.	mean	std.dev.	mean	std.dev.	mean	std.dev.
Spring Wheat									
[illegible]	75	158.54	13.51	233.50	6.94	36.20	6.66	74.96	14.15
	76	153.11	3.08	229.61	8.46	36.95	4.29	76.50	8.89
	77	145.51	8.08	220.59	6.31	36.20	4.66	75.08	10.40
1616	75	167.93	3.82	224.63	4.86	27.66	1.21	56.70	3.90
	76	150.92	5.65	221.44	6.62	34.12	1.64	70.52	3.63
	77	141.93	3.67	220.28	3.79	37.73	1.71	78.35	4.79
1619	76	133.90	11.59	214.07	15.10	38.40	10.11	80.17	21.99
	77	128.73	15.66	285.89	24.76	73.12	16.45	157.16	37.29
	78	144.94	2.81	240.40	17.42	45.68	7.70	95.46	16.44
1637	75	158.48	12.68	237.32	4.65	38.03	4.76	78.84	9.64
	76	148.73	3.80	217.39	6.40	31.81	4.34	68.66	4.30
	77	140.12	7.10	224.61	11.85	40.56	5.38	84.49	11.00
	78	154.94	2.94	245.80	13.33	43.65	6.48	90.86	14.36
1652	76	146.85	5.99	211.16	6.33	31.17	2.34	64.31	11.19
	77	150.90	7.34	211.04	10.55	29.19	6.69	60.14	13.89
1677	75	132.51	13.03	200.58	5.64	32.78	7.25	68.07	15.49
	76	135.00	8.43	186.15	11.50	24.83	7.18	51.15	15.25
	77	122.51	12.53	213.24	12.43	43.17	8.83	90.73	19.32
	78	140.80	8.42	251.82	19.37	52.70	11.87	111.02	25.95
[illegible]	75	123.57	17.65	207.90	11.09	40.27	4.84	84.33	10.68
	76	138.35	2.68	193.79	4.72	26.94	2.04	55.44	4.99
	77	114.88	8.62	226.27	8.70	52.97	4.50	111.39	17.95
	78	147.80	15.04	256.74	21.65	52.36	15.06	108.94	32.94
Mean		142.65		224.97		39.41		82.32	
Winter Wheat									
[illegible]	76	40.87	11.56	165.36	3.46	54.68	4.61	124.49	13.02
	77	39.22	3.57	162.10	7.45	54.10	3.37	122.88	8.60
	78	77.86	8.65	167.36	8.61	41.77	7.12	89.50	16.37
[illegible]	76	90.61	6.32	165.16	5.30	35.39	3.33	74.55	7.00
	77	79.57	4.21	186.83	5.85	49.79	3.24	107.26	7.04
[illegible]	76	11.24	8.62	139.48	9.54	49.07	4.62	128.24	16.77
	77	31.06	7.12	149.84	8.38	51.39	3.95	118.78	11.20
Mean		52.92		162.30		48.03		109.39	

T_b = Julian date on which GRABS = 2 before peak

T_a = Julian date on which GRABS = 2 after peak

8

DESCRIPTION OF GRAPHS

In referencing the various graphs, the title in the upper right hand corner of each graph will be used.

I. SPRING WHEAT

A. "Segment: 1602-1686"

In these graphs (one for each segment), each curve represents crop growth characteristics for a particular year (for curve identification refer to the legend on each graph). The solution vector associated with each curve as well as the location of the segment are also given.

B. "Spring Wheat Average"

This is a curve representing the average of all the curves plotted in the seven graphs "Segment: 1602-1686".

C. "All Segments**All Years"

These are all the curves of the seven graphs "Segment: 1602-1686" plotted on one graph.

D. "Year: 1975-1978"

These curves are those in "Segment: 1602-1686" but are grouped such as to compare segments by year. That is, holding the year constant across all the segments.

E. "Segment Averages by Year"

This graph represents an average of the 1975 curves across all the segments, an average of 1976 curves across all the segments, etc.

F. "Yearly Averages by Segment"

The curves represent a computed average of the curves within each segment for all years in which data was available for the segment.

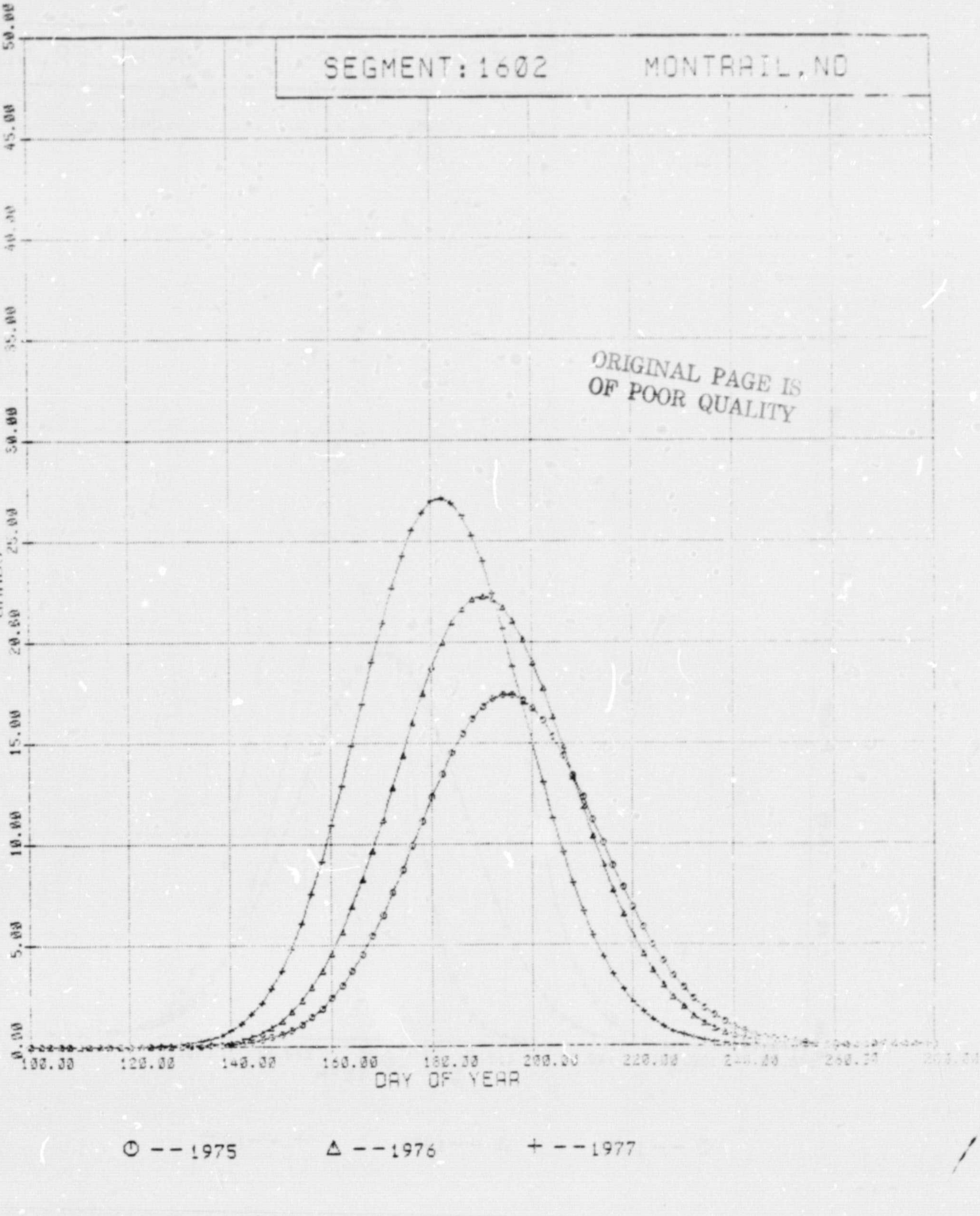
II. WINTER WHEAT

A complete parallel of the preceding graphs follows for winter wheat.

SPRING WHEAT

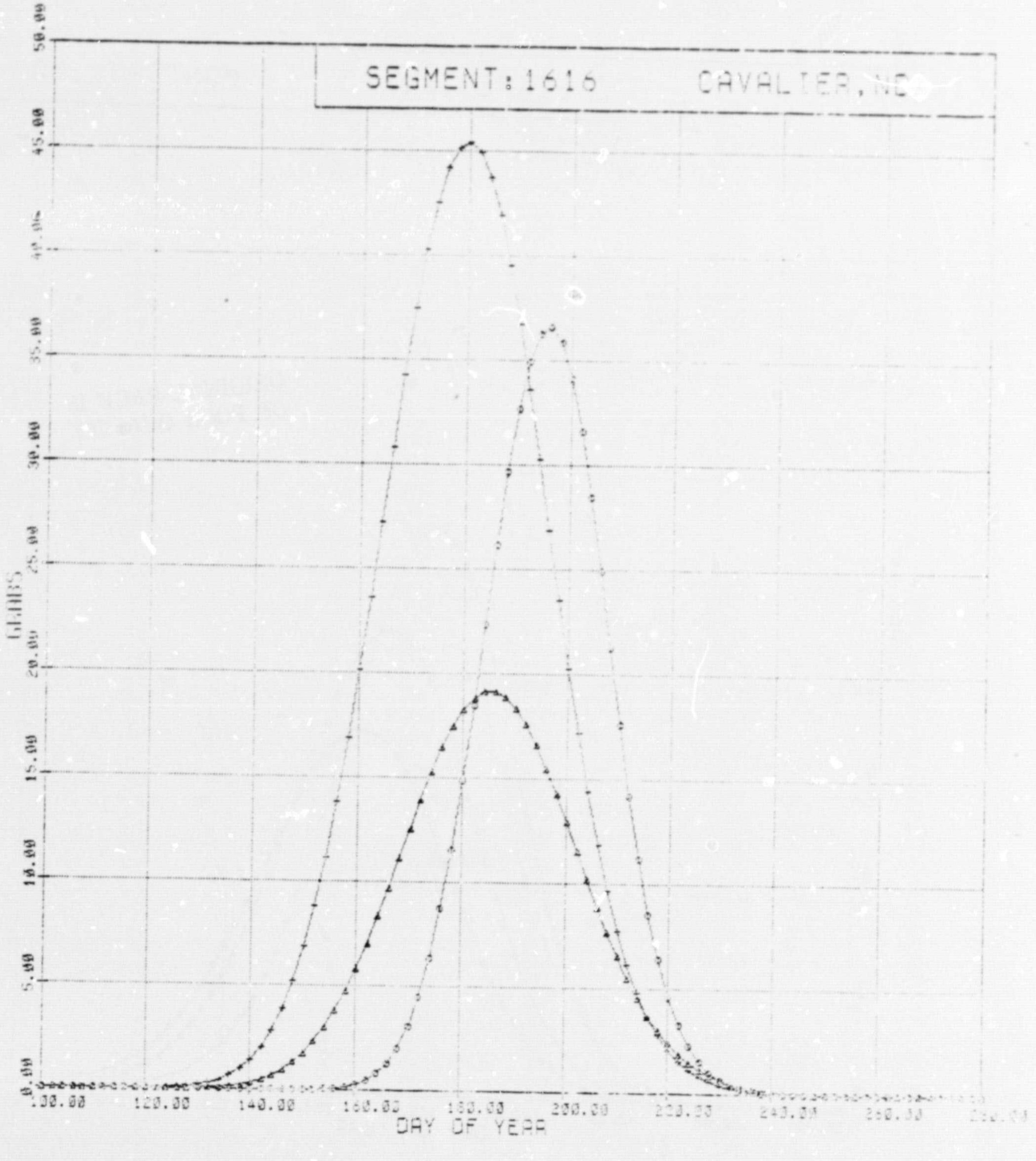
[illegible]

1975	[illegible]	[illegible]	[illegible]
1976	[illegible]	[illegible]	[illegible]
1977	B1=60.81998	B2=-0.00292	B3=[illegible]



F=T**B1*E/(B2*T**B3)

1975	B1=[illegible]	B2=[illegible]	B3=[illegible]
1976	B1=[illegible]	B2=[illegible]	B3=[illegible]
1977	B1=[illegible]	B2=[illegible]	B3=[illegible]

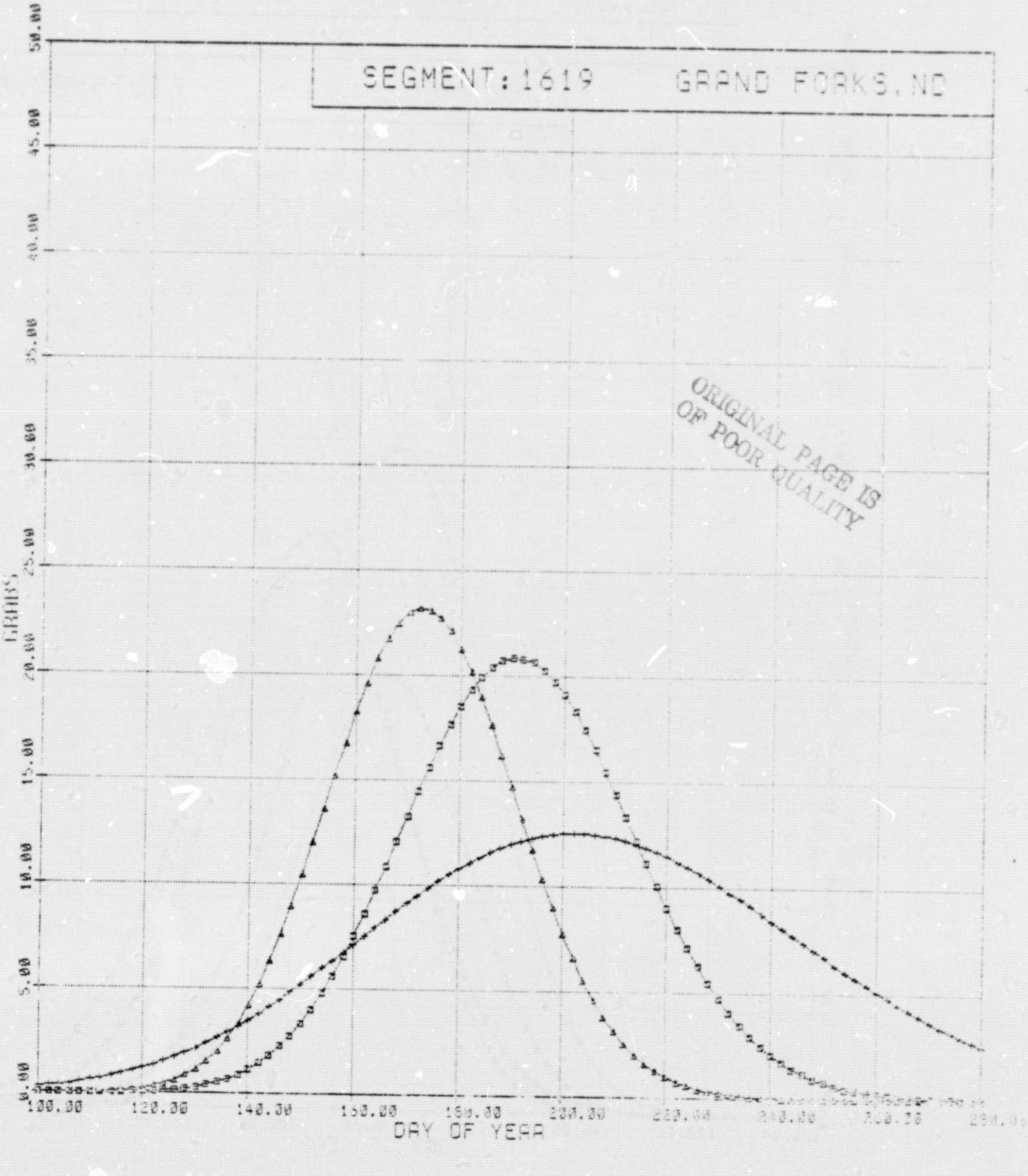


○ -- 1975 △ -- 1976 + -- 1977

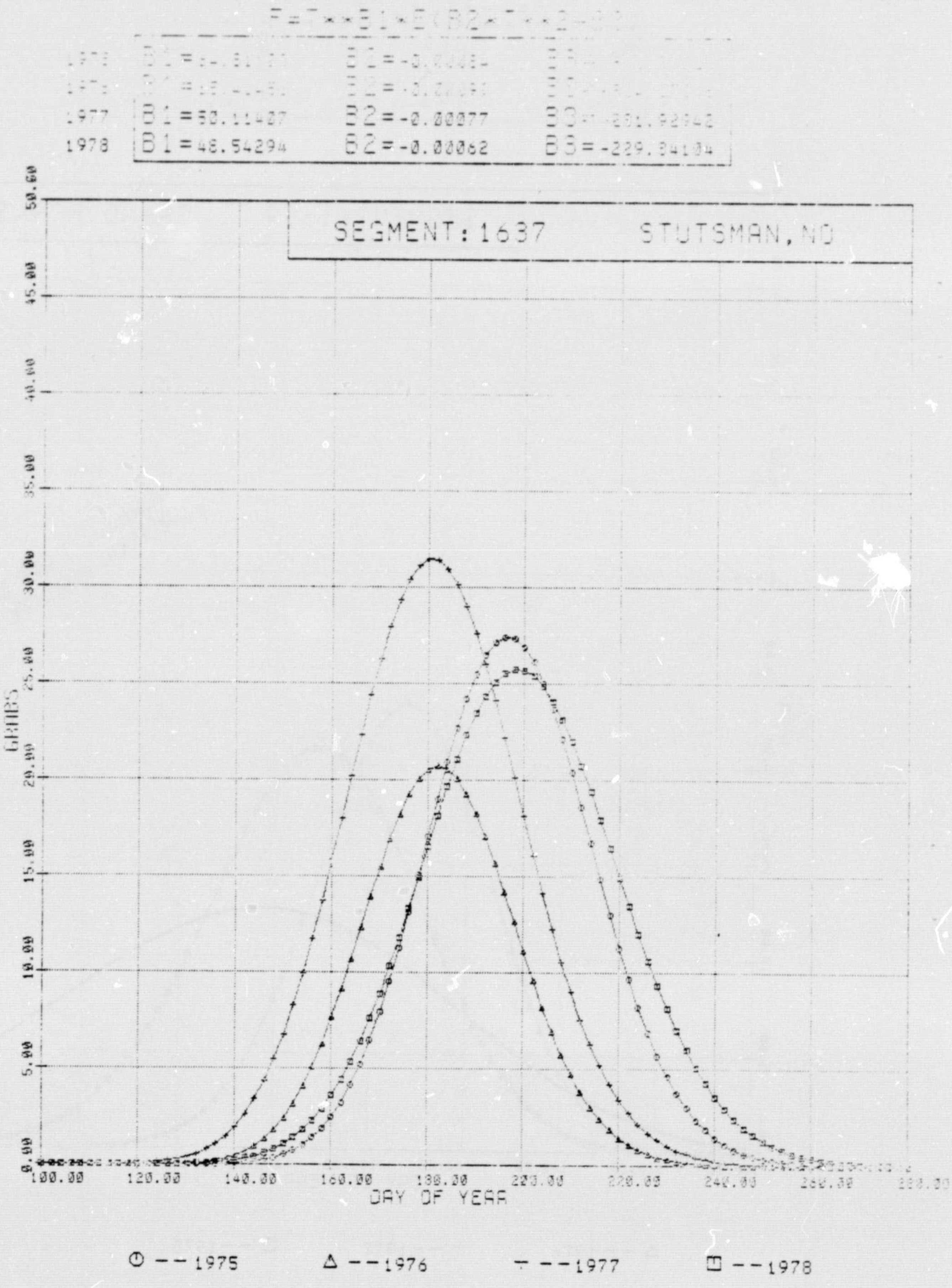
12

F=T**B1*E(B2*T**2-B3)

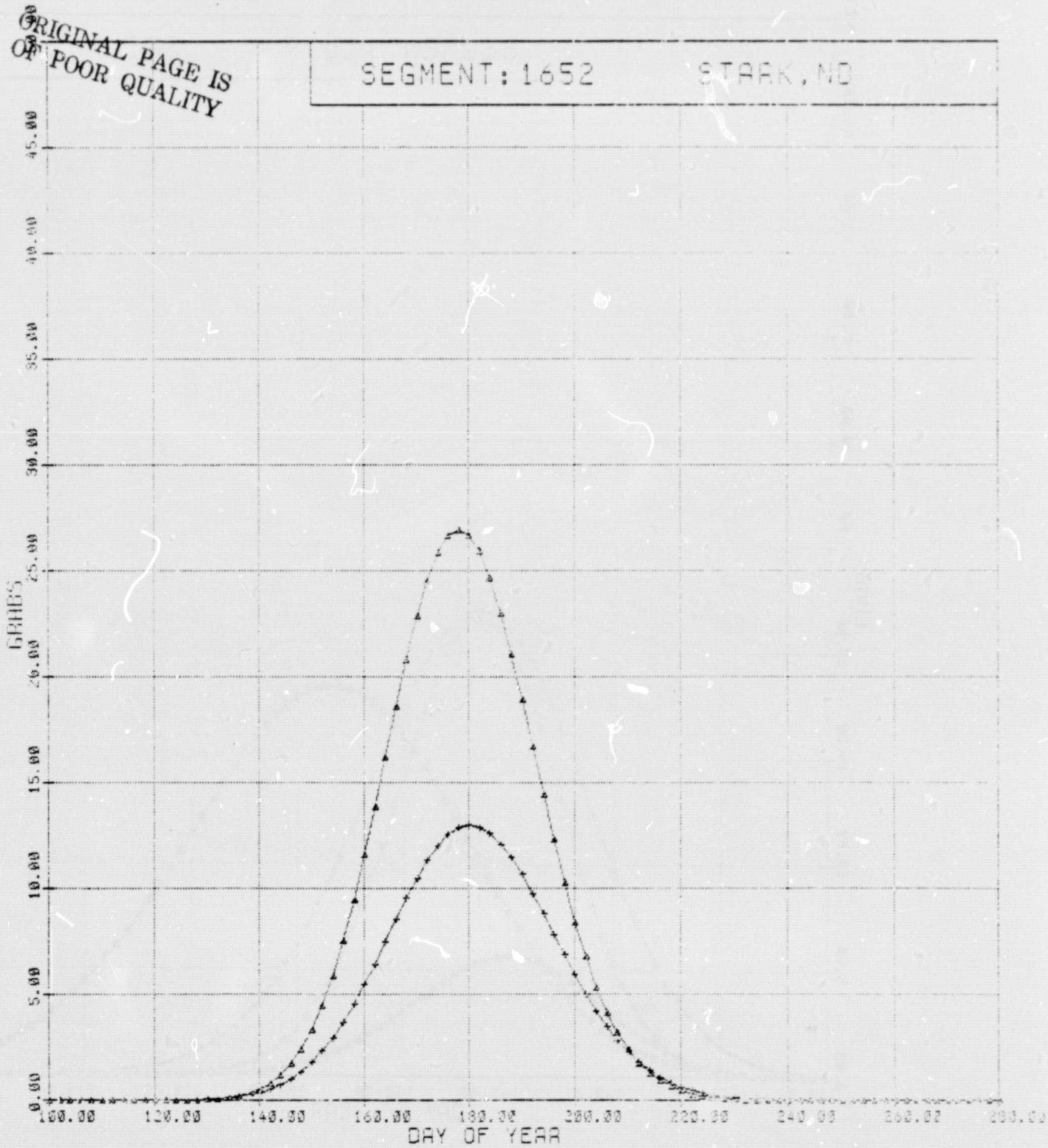
[illegible]	B1=[illegible]	B2=[illegible]	B3=[illegible]
[illegible]	B1=[illegible]	B2=[illegible]	B3=[illegible]
1978	B1=[illegible]	B2=[illegible]	B3=[illegible]



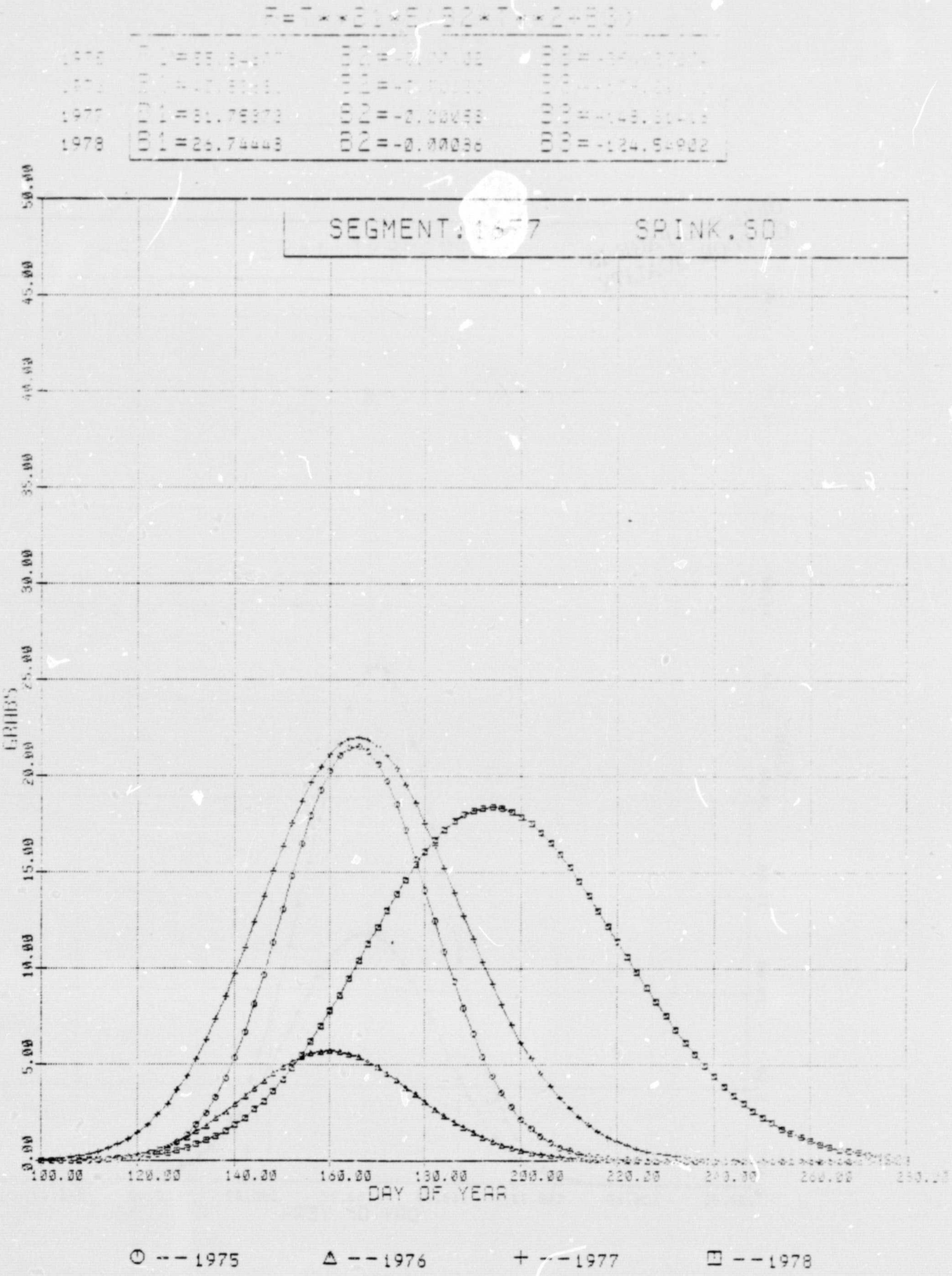
△ --1976 + --1977 ⊡ --1978


1977 B1 = 50.11407 B2 = -0.00077
1978 B1 = 48.54294 B2 = -0.00062 B3 = -229.84104
SEGMENT: 1637 STUTSMAN, ND
GRABS
DAY OF YEAR
100.00
120.00
140.00
160.00
180.00
200.00
220.00
240.00
260.00
280.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
○ --1975
△ --1976
+ --1977
□ --1978

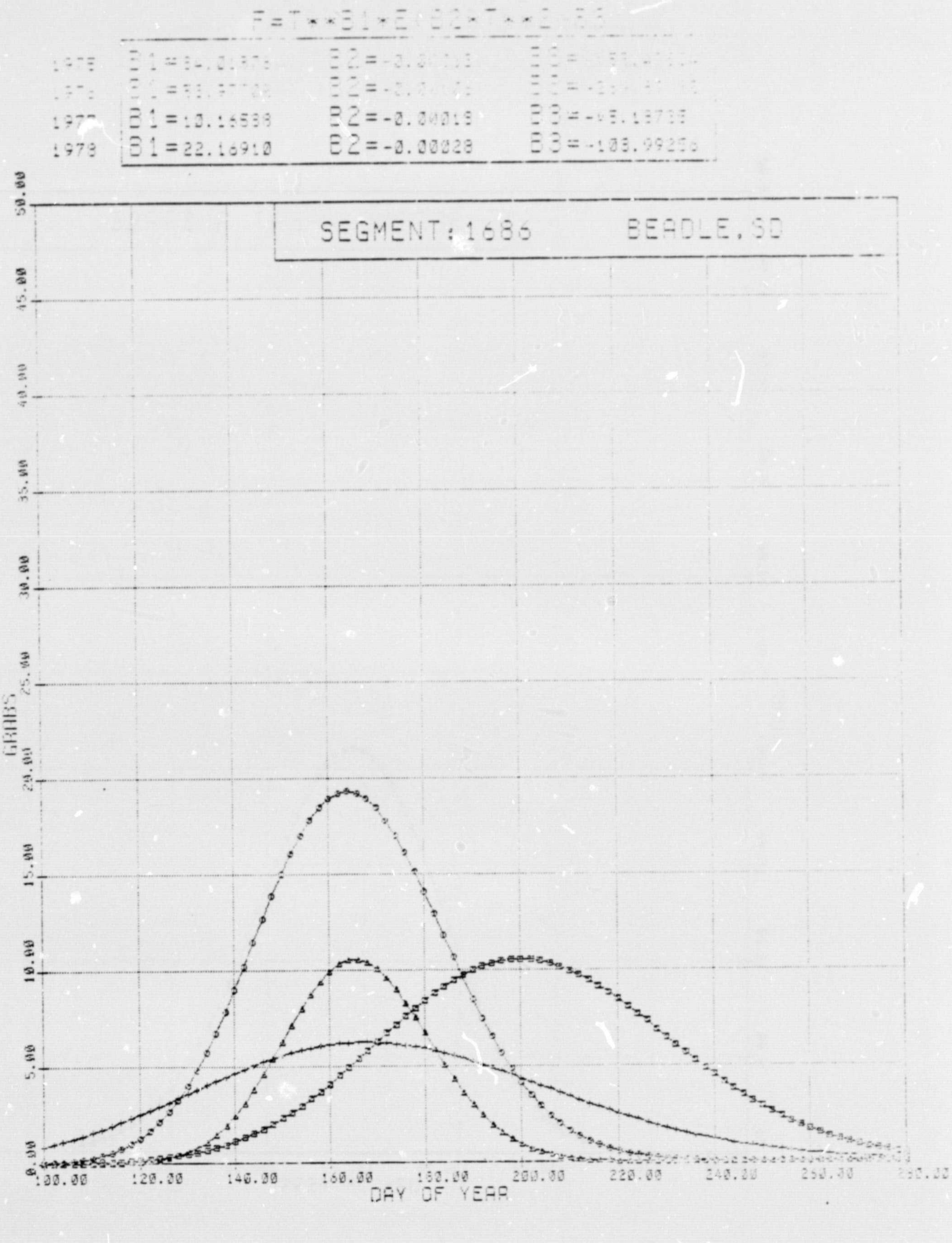
F=T**B1*E(B2*T**2+B3)



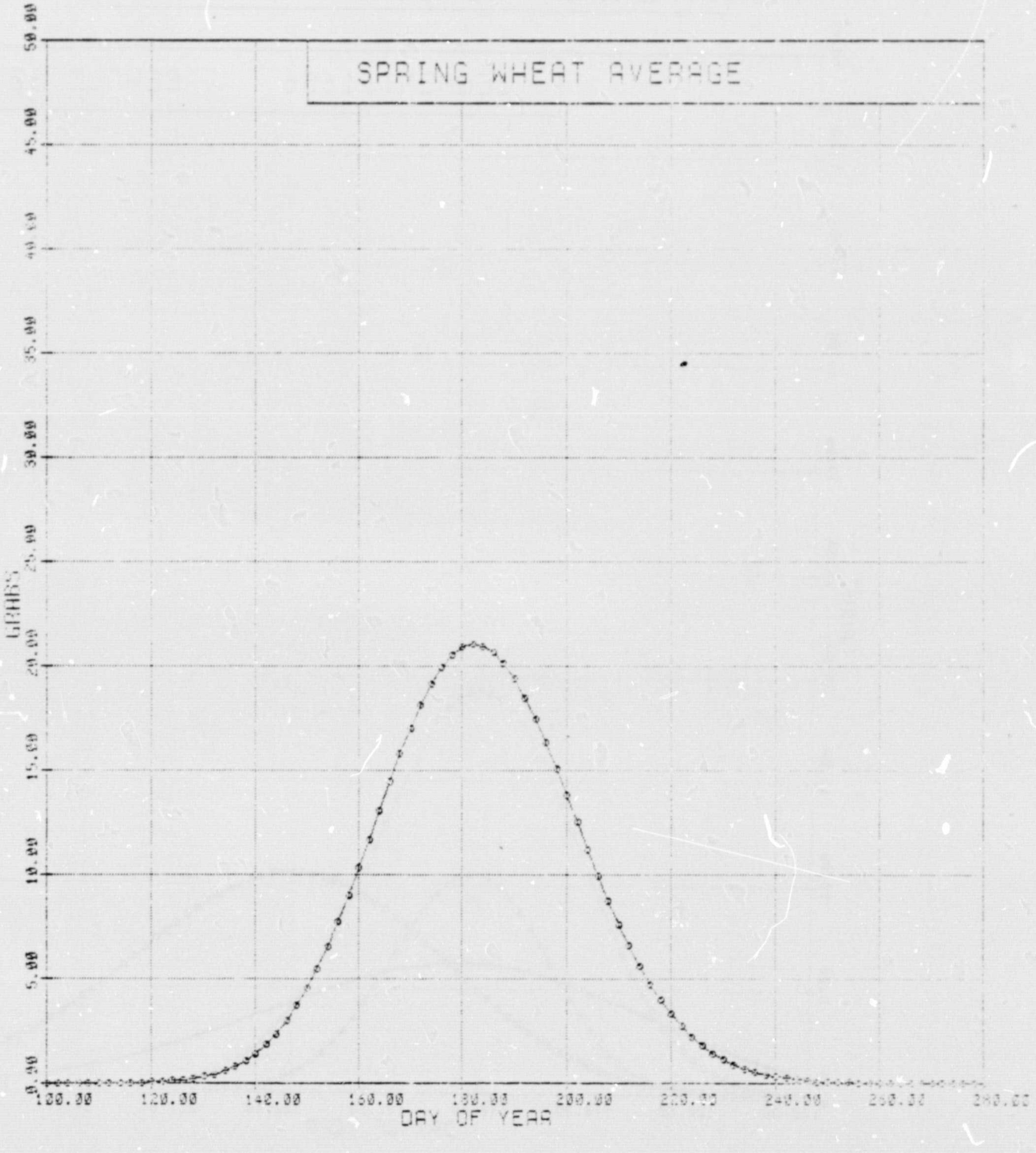
Δ -- 1976 + -- 1977



1978 B1=25.74448 B2=-0.00036 B3=-124.54902
SEGMENT:
SPINK.SD
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
100.00
120.00
140.00
160.00
180.00
200.00
220.00
240.00
260.00
DAY OF YEAR
O --- 1975
Δ --- 1976
+ --- 1977
⊞ --- 1978

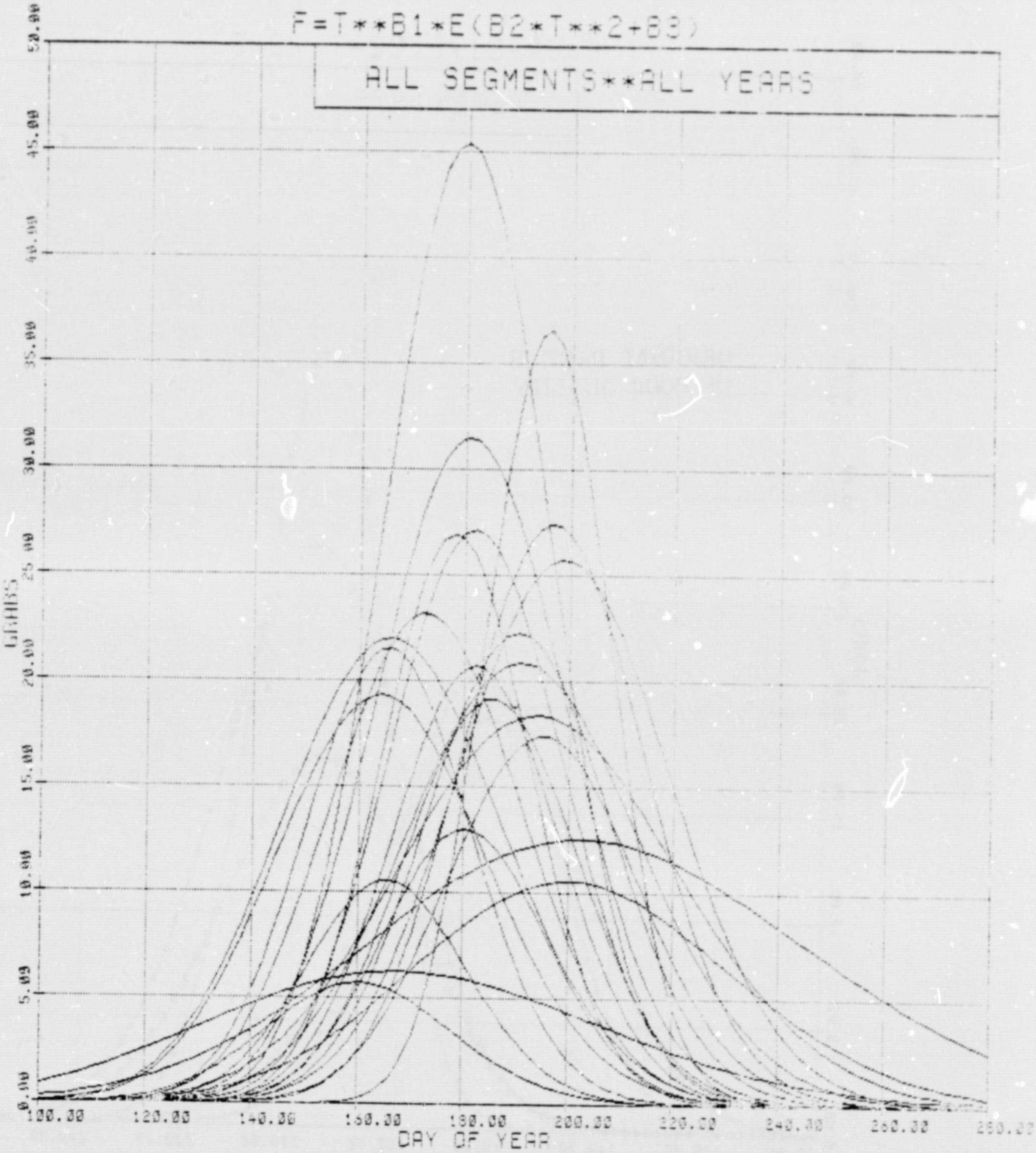

1977 B1=10.16538 B2=-0.00019
1978 B1=22.16910 B2=-0.00028
SEGMENT:1686 BEADLE,SD
GRAMS
DAY OF YEAR
○ --1975
△ --1976
+ --1977
□ --1978

F=T**B1*E(B2*T**2+B3)

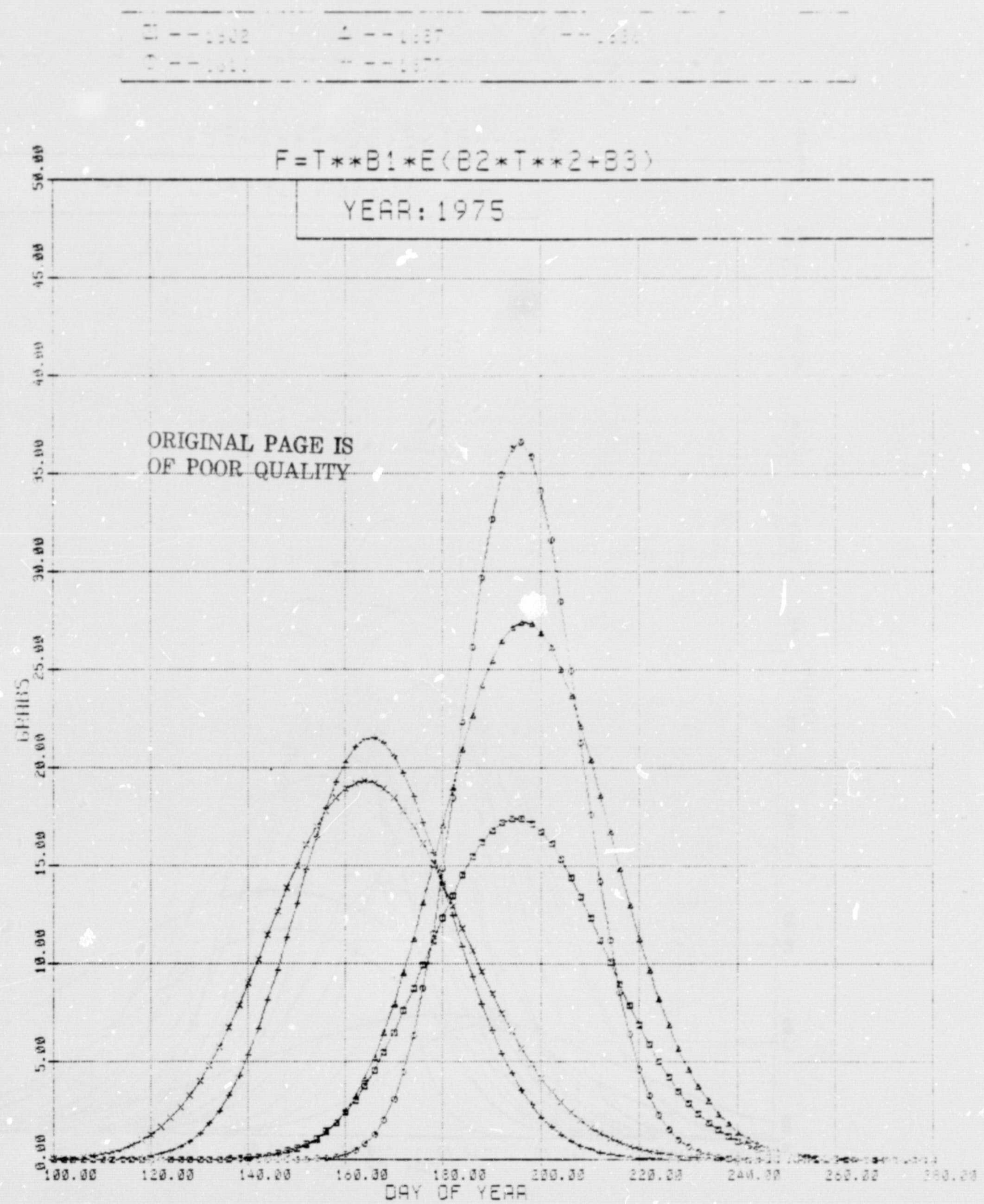


① -- AVG.

SPRING WHEAT



869



F=T**B1*E(B2*T**2+B3)
YEAR: 1975
ORIGINAL PAGE IS
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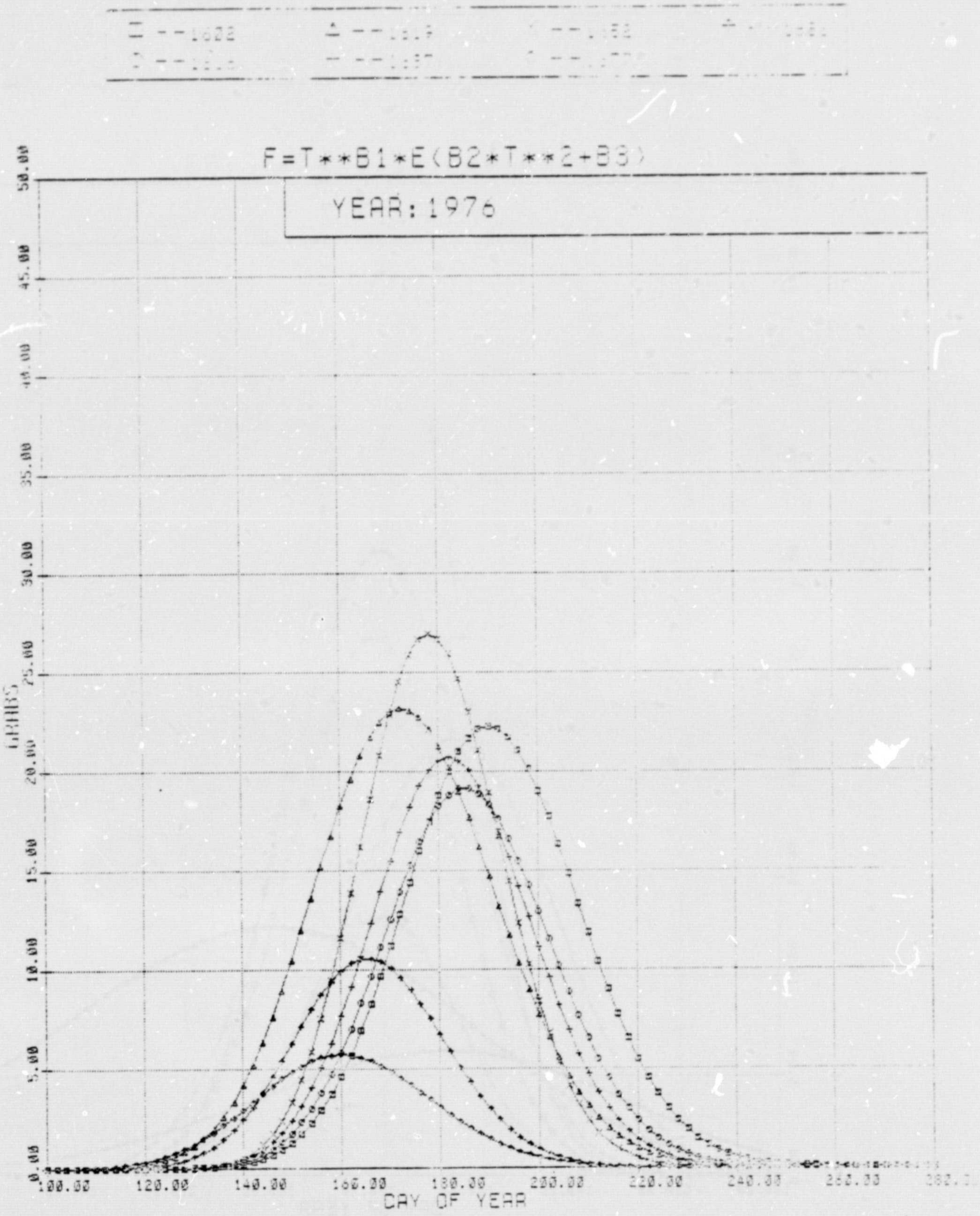
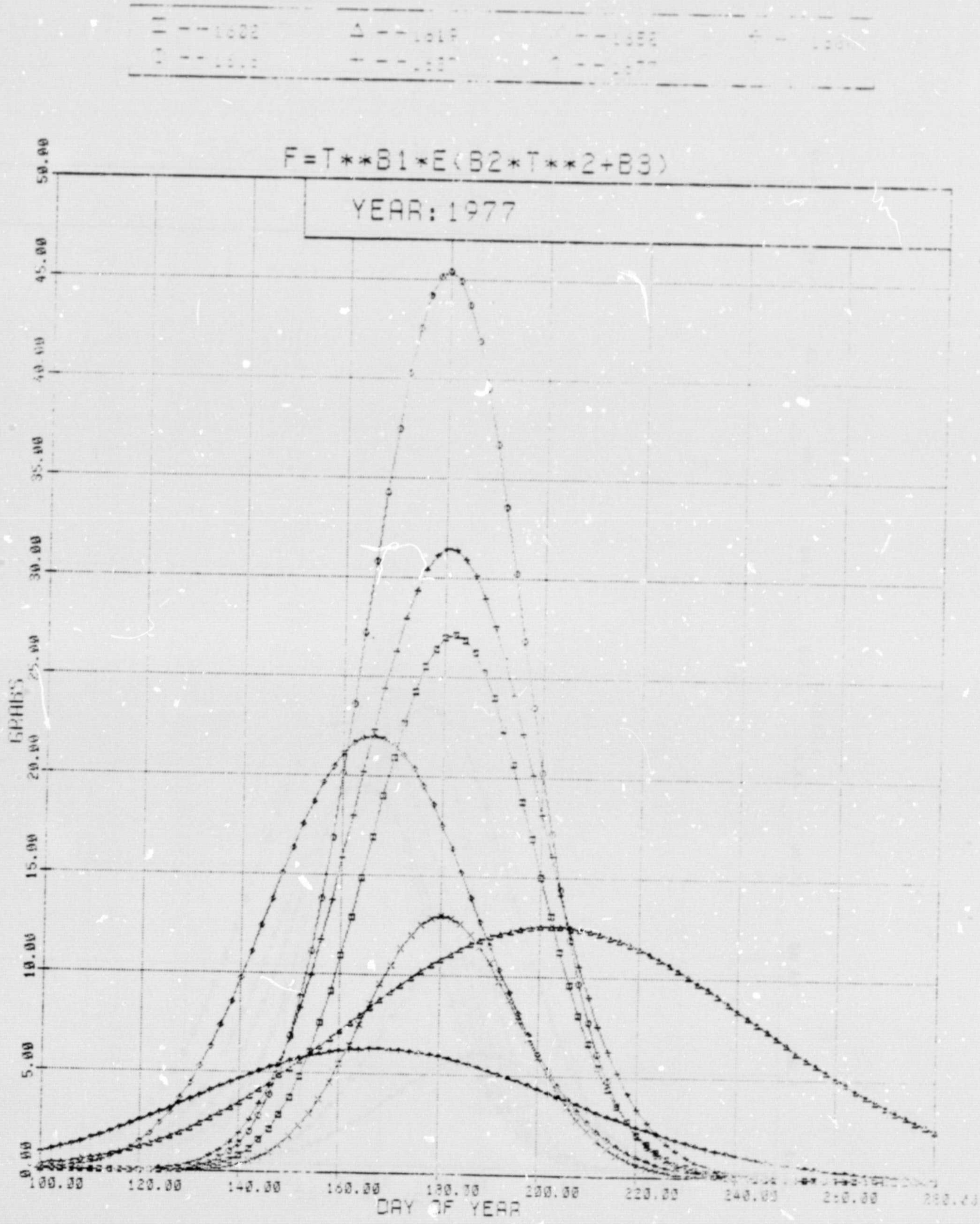
GRAMS
DAY OF YEAR
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
100.00
120.00
140.00
160.00
180.00
200.00
220.00
240.00
260.00
280.00

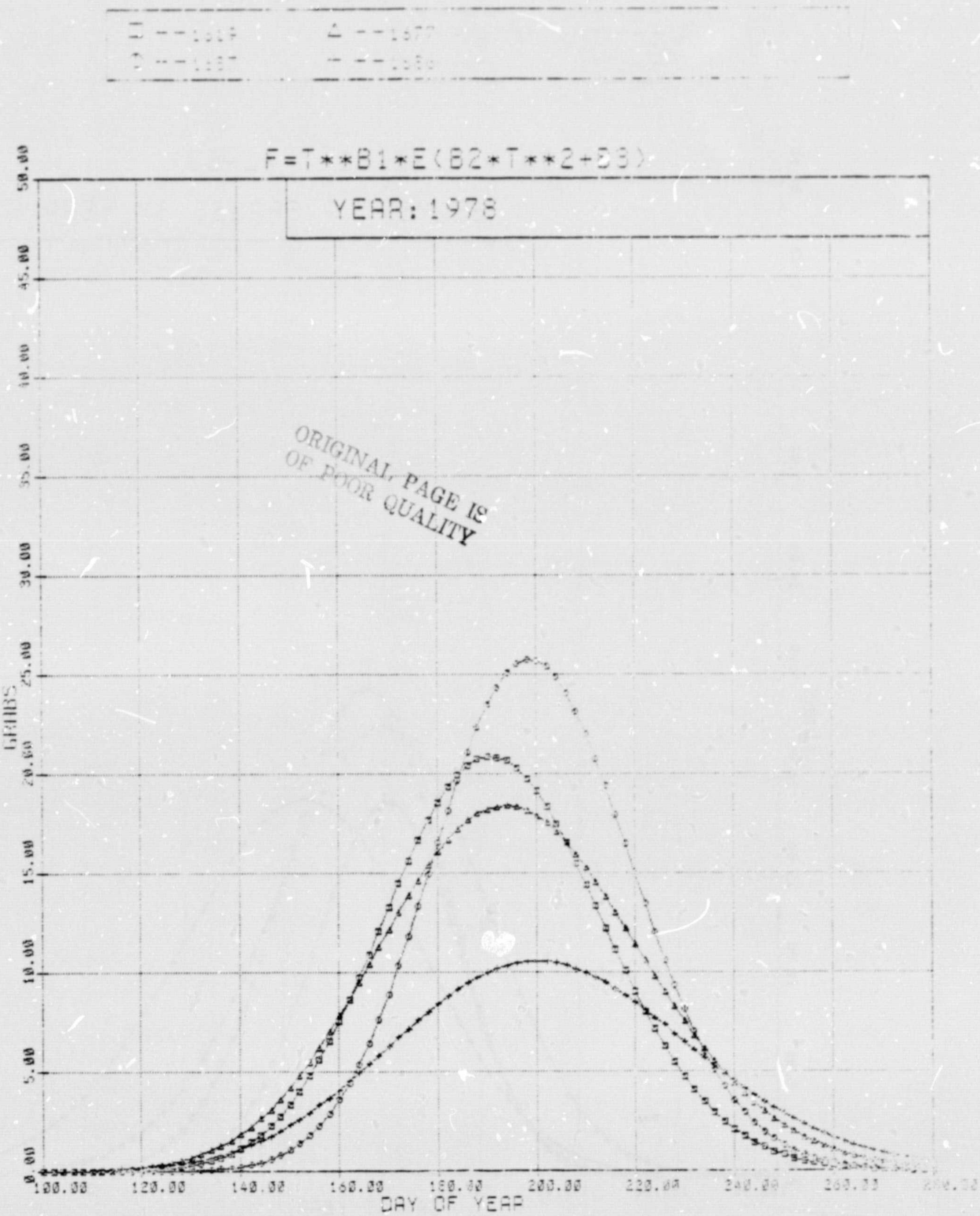
20


F=T**B1*E(B2*T**2+B3)
YEAR:1976
GRAMS
DAY OF YEAR
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
100.00
120.00
140.00
160.00
180.00
200.00
220.00
240.00
260.00

21


F=T**B1*E(B2*T**2+B3)
YEAR: 1977
GRAMS
DAY OF YEAR
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
100.00
120.00
140.00
160.00
180.00
200.00
220.00
240.00

22



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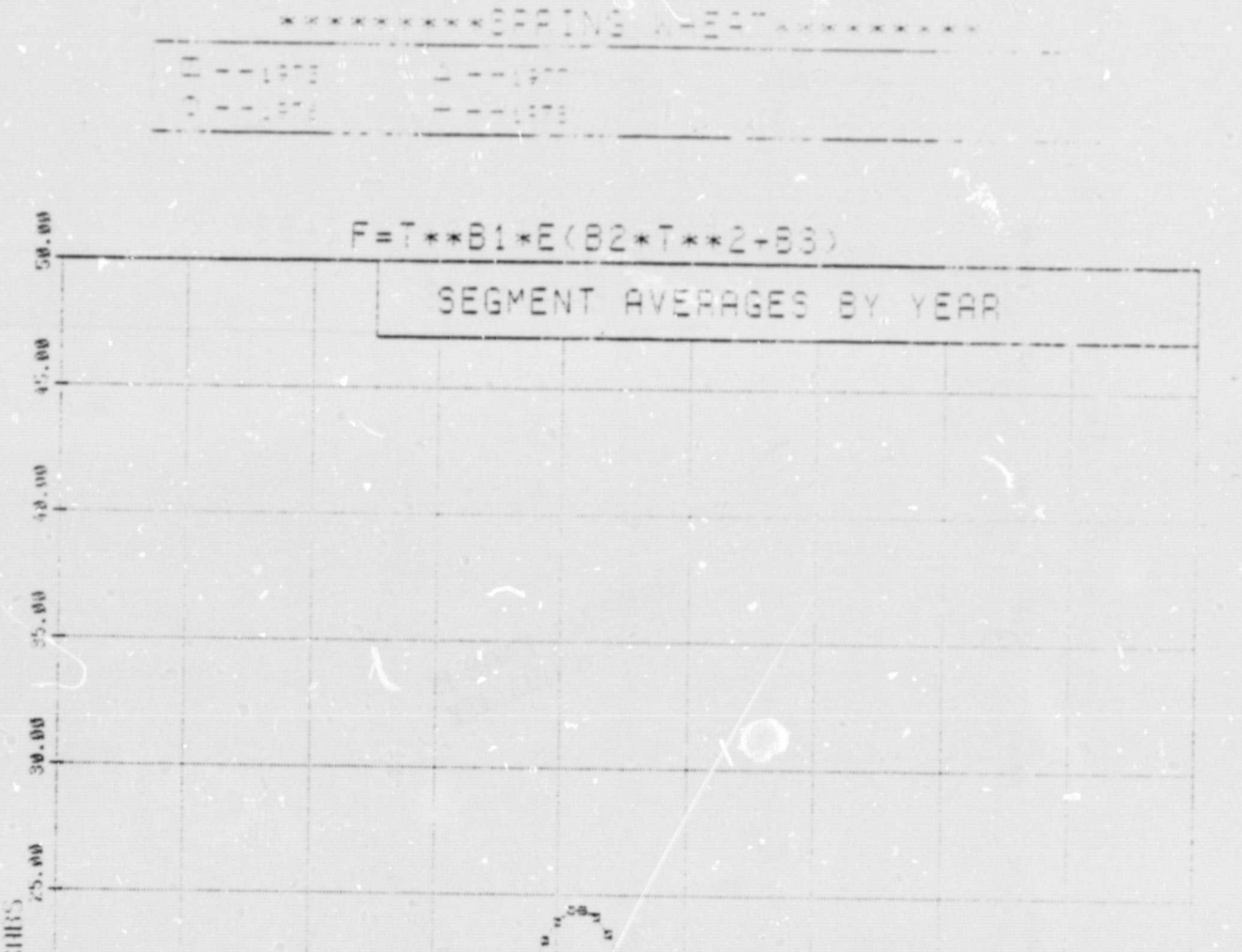
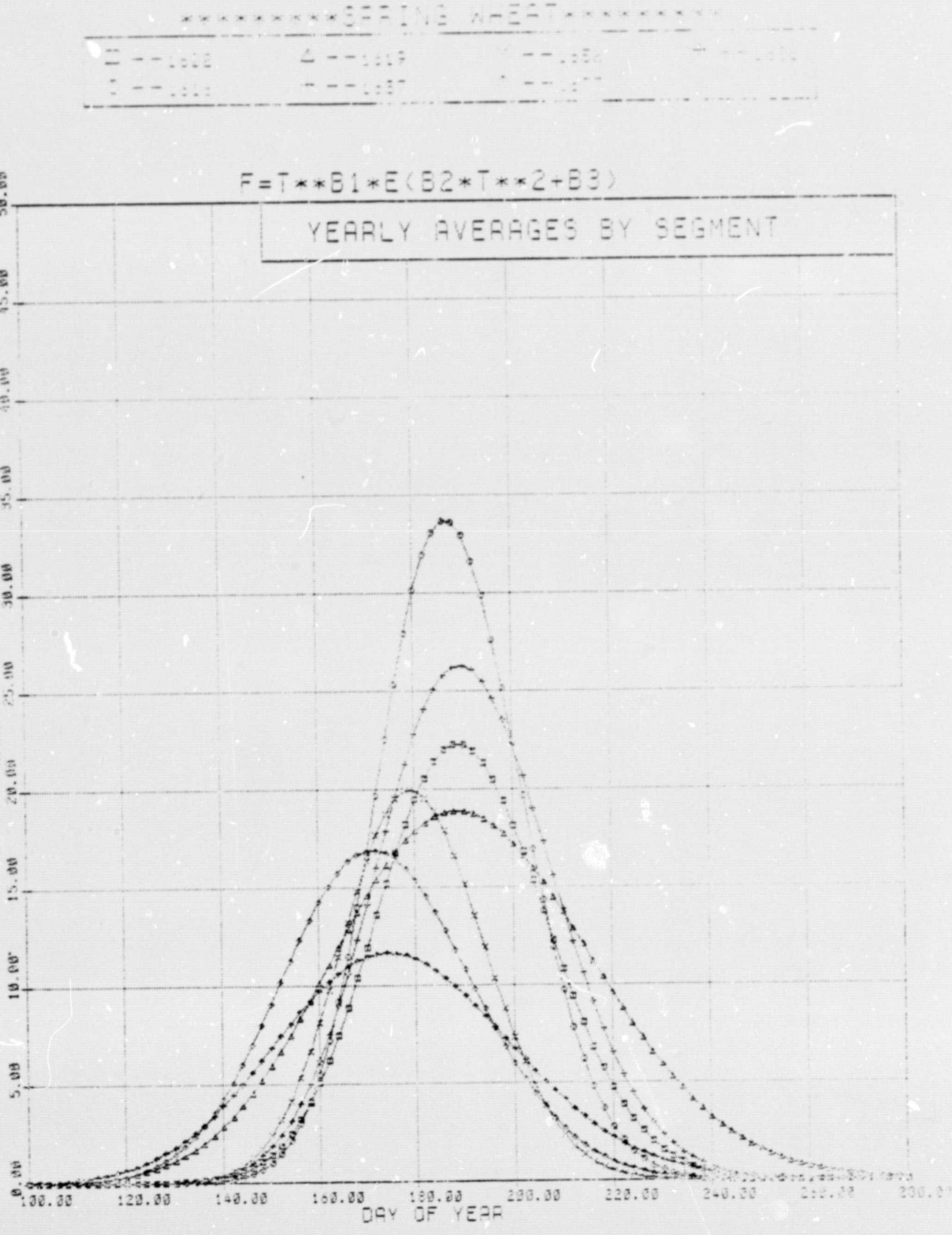
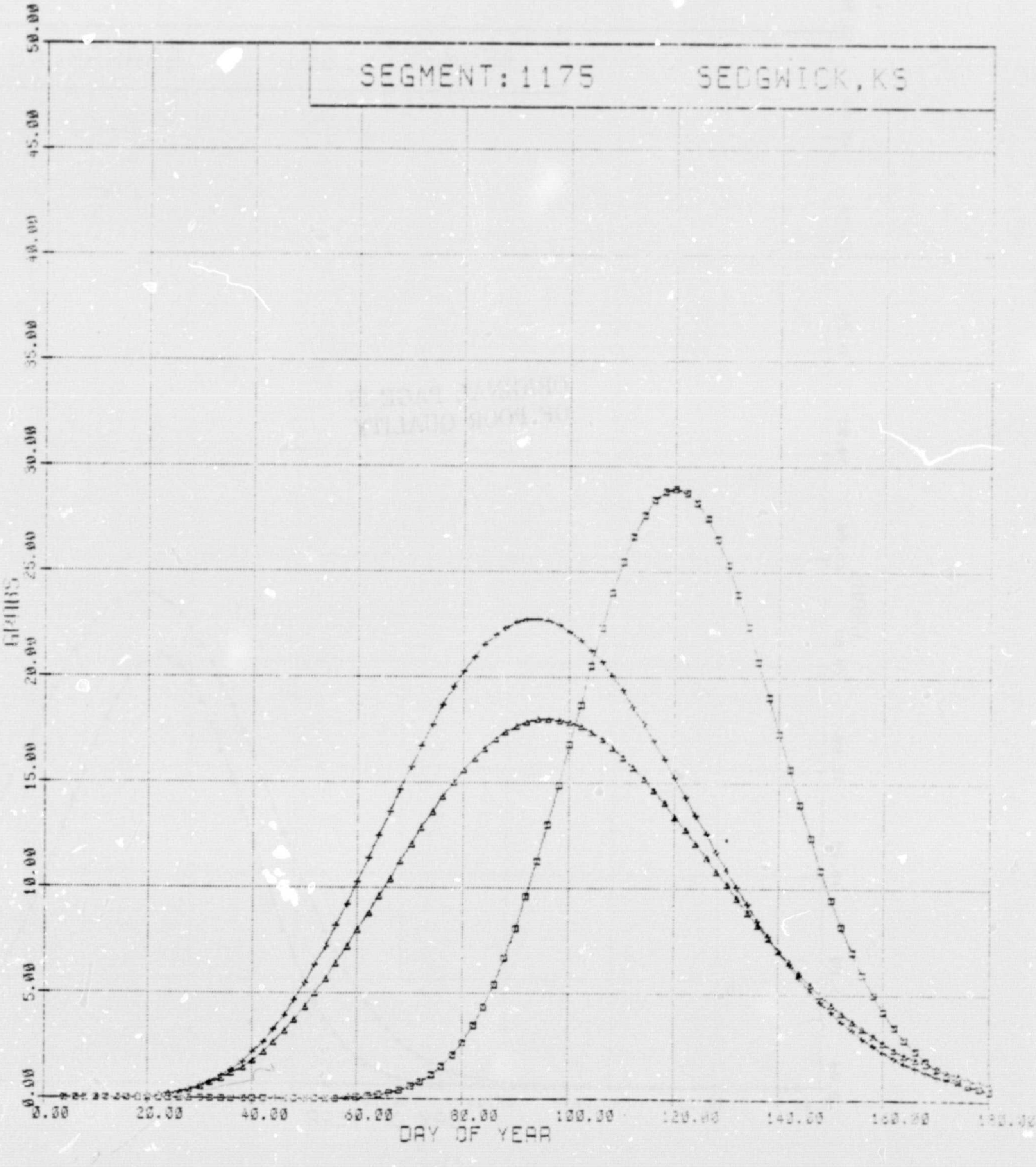

**********SPRING WHEAT**********
F=T**B1*E(B2*T**2+B3)
SEGMENT AVERAGES BY YEAR
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
100.00
120.00
140.00
160.00
180.00
200.00
220.00
240.00
260.00
280.00
DAY OF YEAR


*********SPRING WHEAT*********
F=T**B1*E(B2*T**2+B3)
YEARLY AVERAGES BY SEGMENT
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
GPHRS
100.00
120.00
140.00
160.00
180.00
200.00
220.00
240.00
DAY OF YEAR

WINTER WHEAT

F=T**B1*E(B2*T**2+B3)

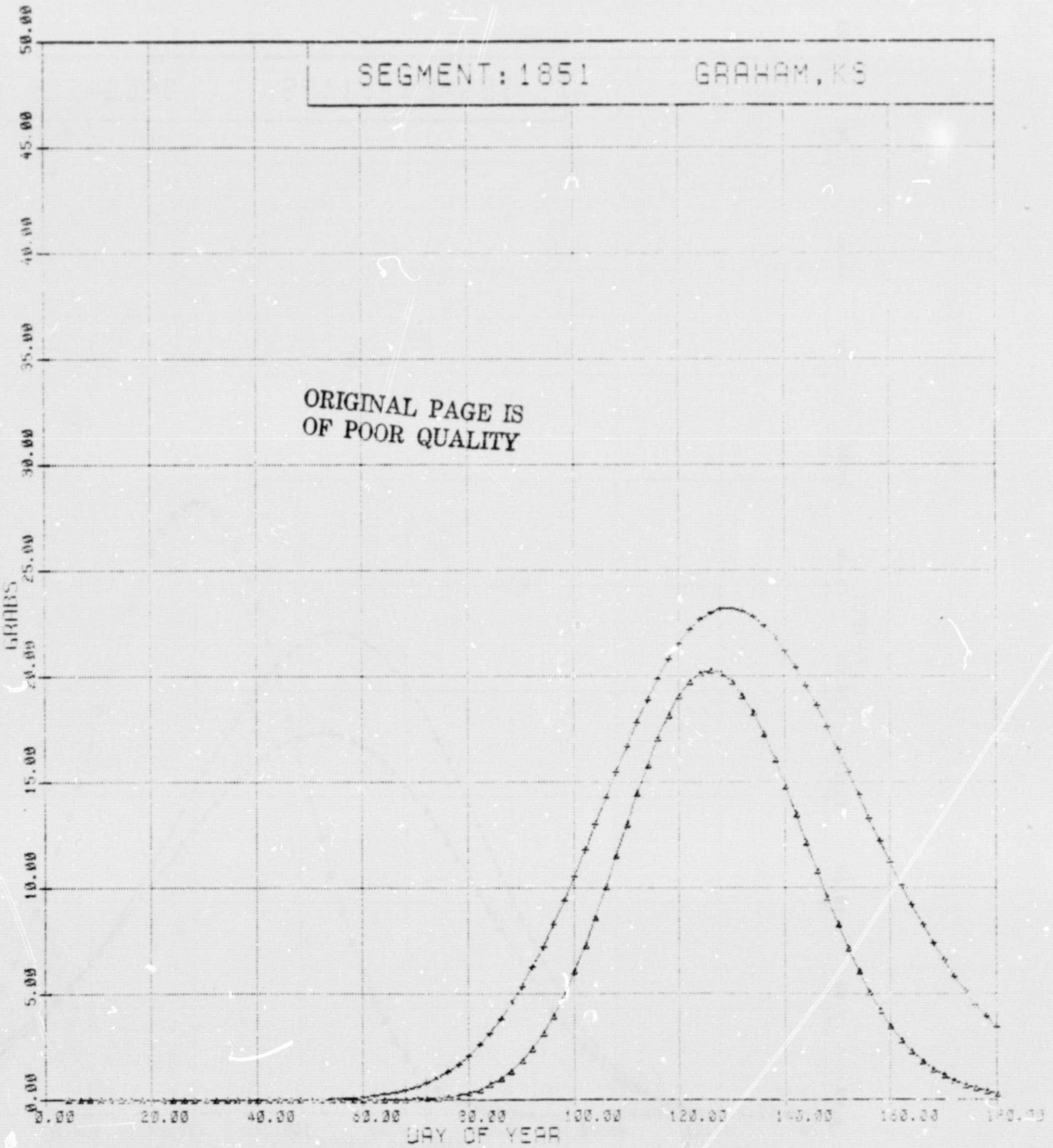
1976	B1=[illegible]	B2=-0.00[illegible]	B3=[illegible]
1977	B1=[illegible]	B2=-0.00[illegible]	B3=[illegible]
1978	B1=18.33503	B2=-0.00066	B3=-77.35357



△ --1976 + --1977 ⊡ --1978

F=T**B1*E(B2*T**2+B3)

1976	B1=[illegible]	B2=[illegible]	B3=[illegible]
1977	B1=[illegible]	B2=[illegible]	B3=[illegible]



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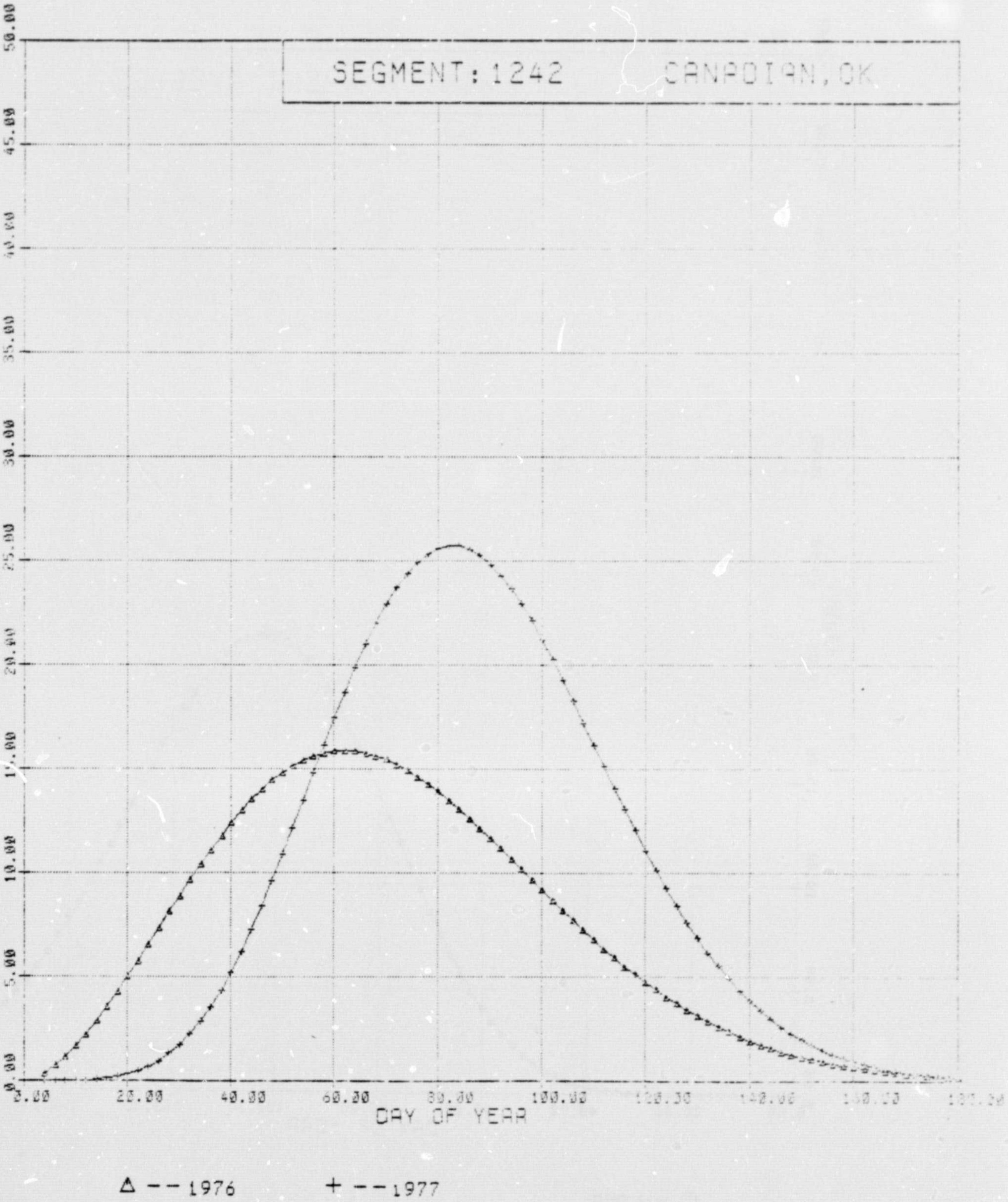
△ --- 1976 + --- 1977

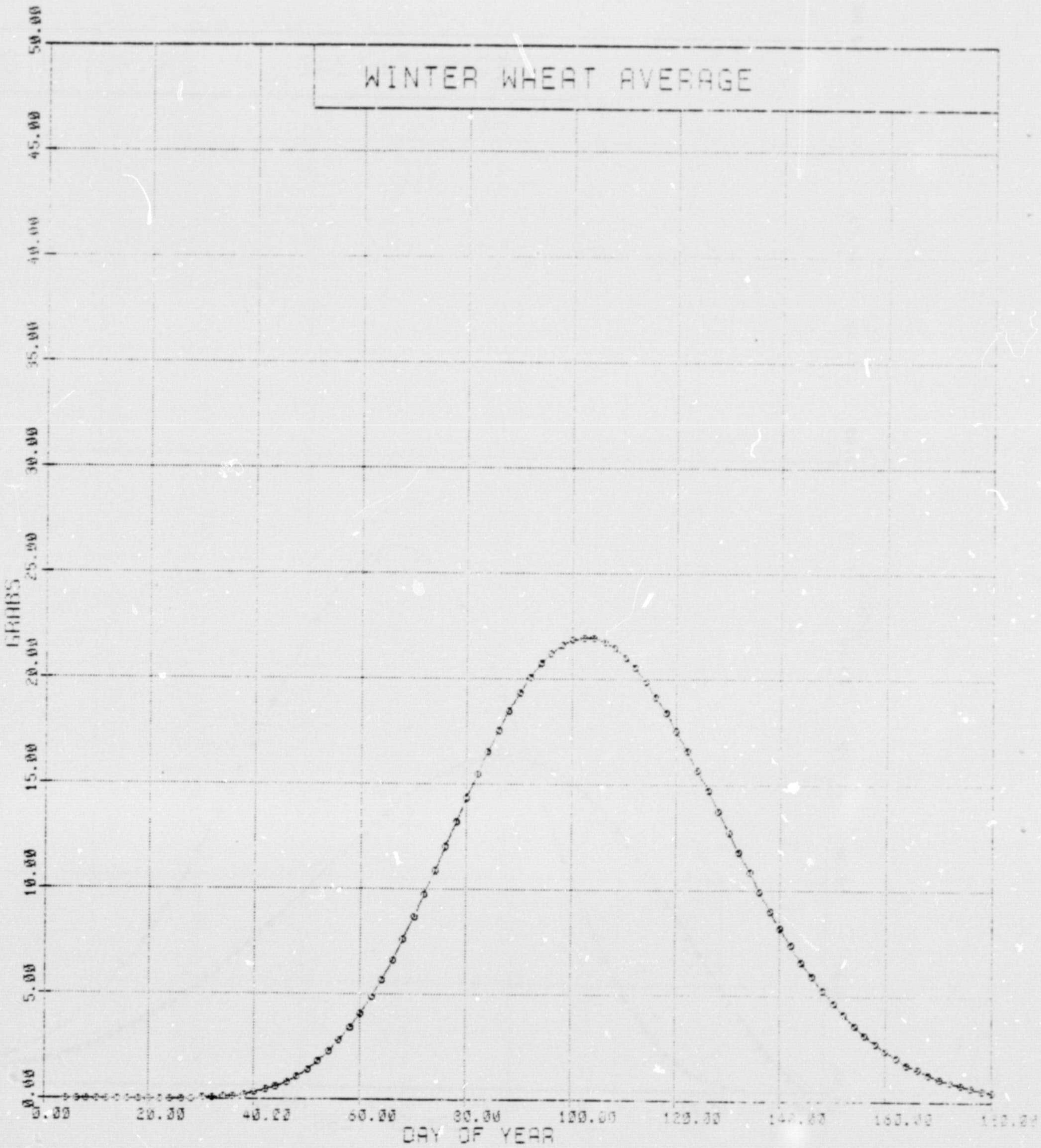
28 633

F=T**B1*E(B2*T**2+B3)

1976 B1=[illegible] B2=[illegible] B3=[illegible]
1977 B1=[illegible] B2=[illegible] B3=[illegible]



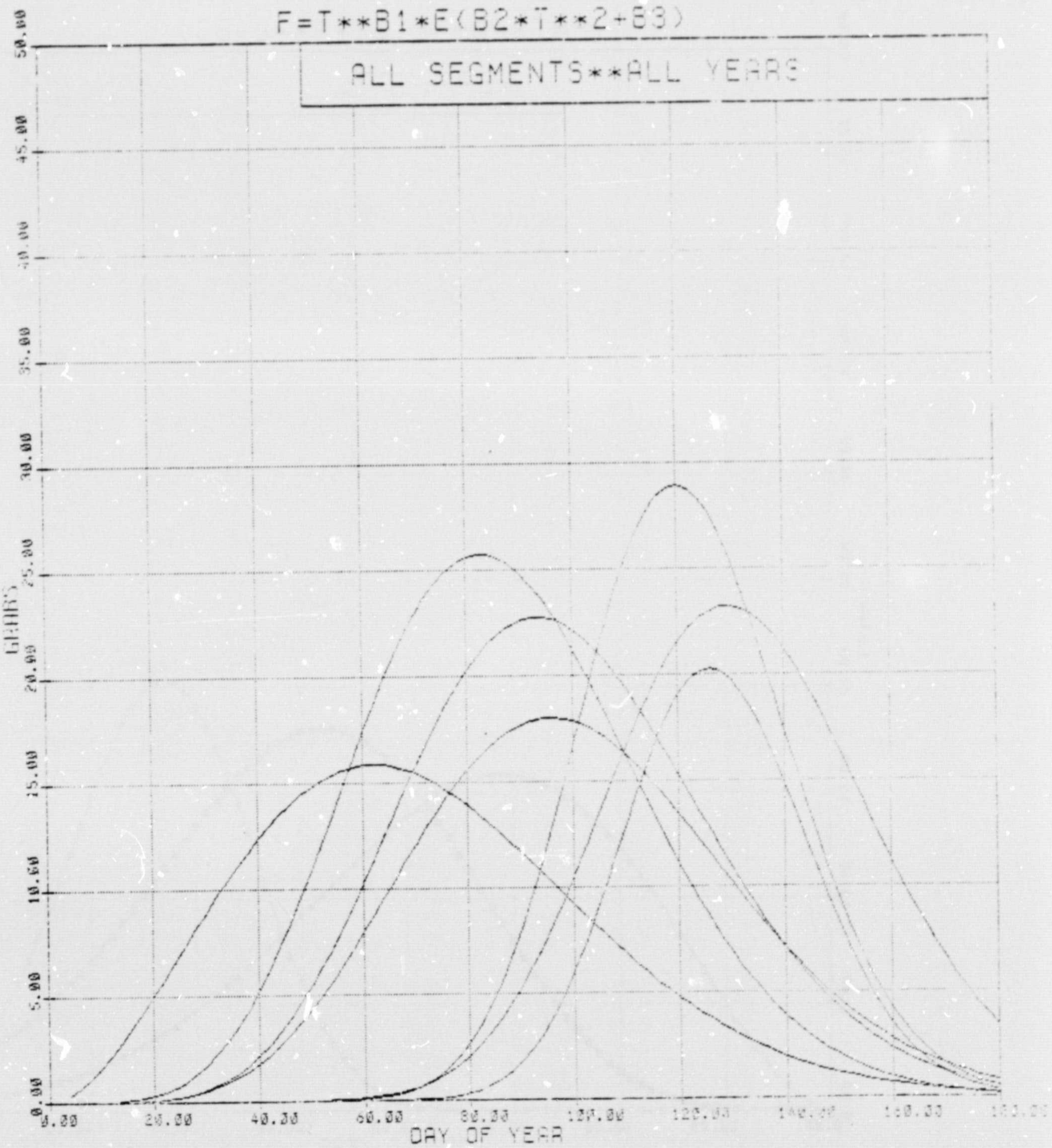
F=T**B1*E(B2*T**2-B3

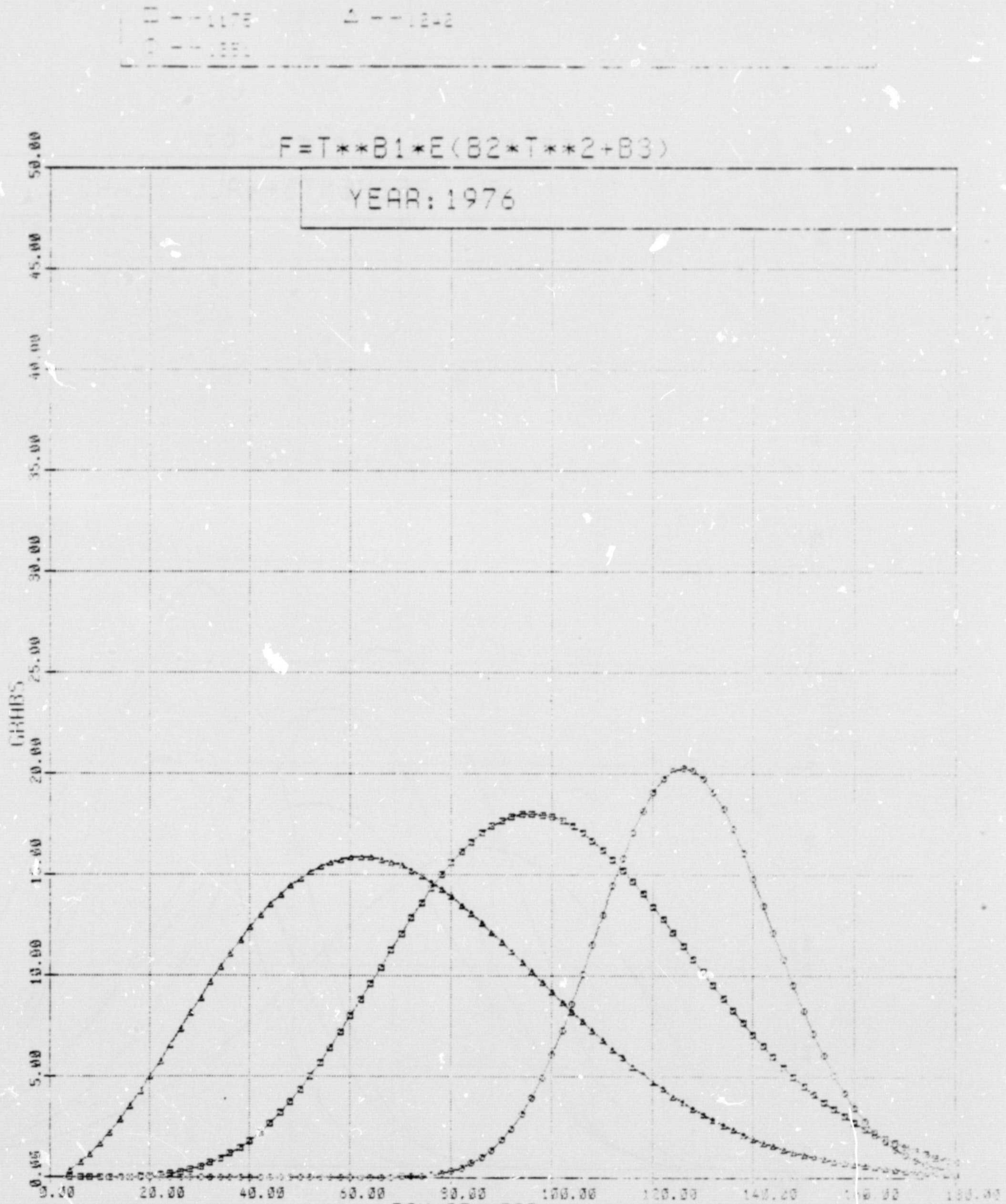


⊙ -- AVG.

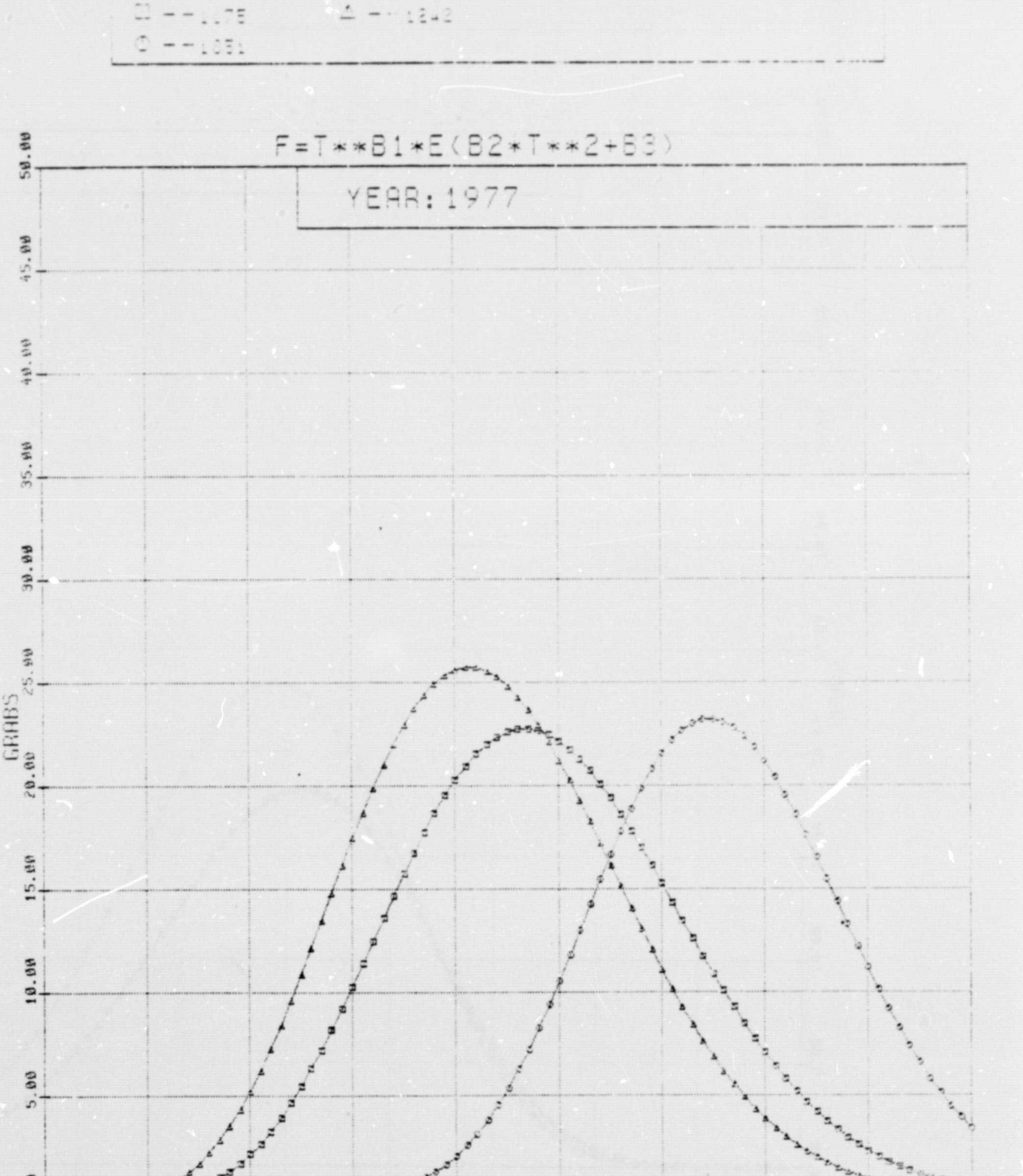
30

WINTER WHEAT

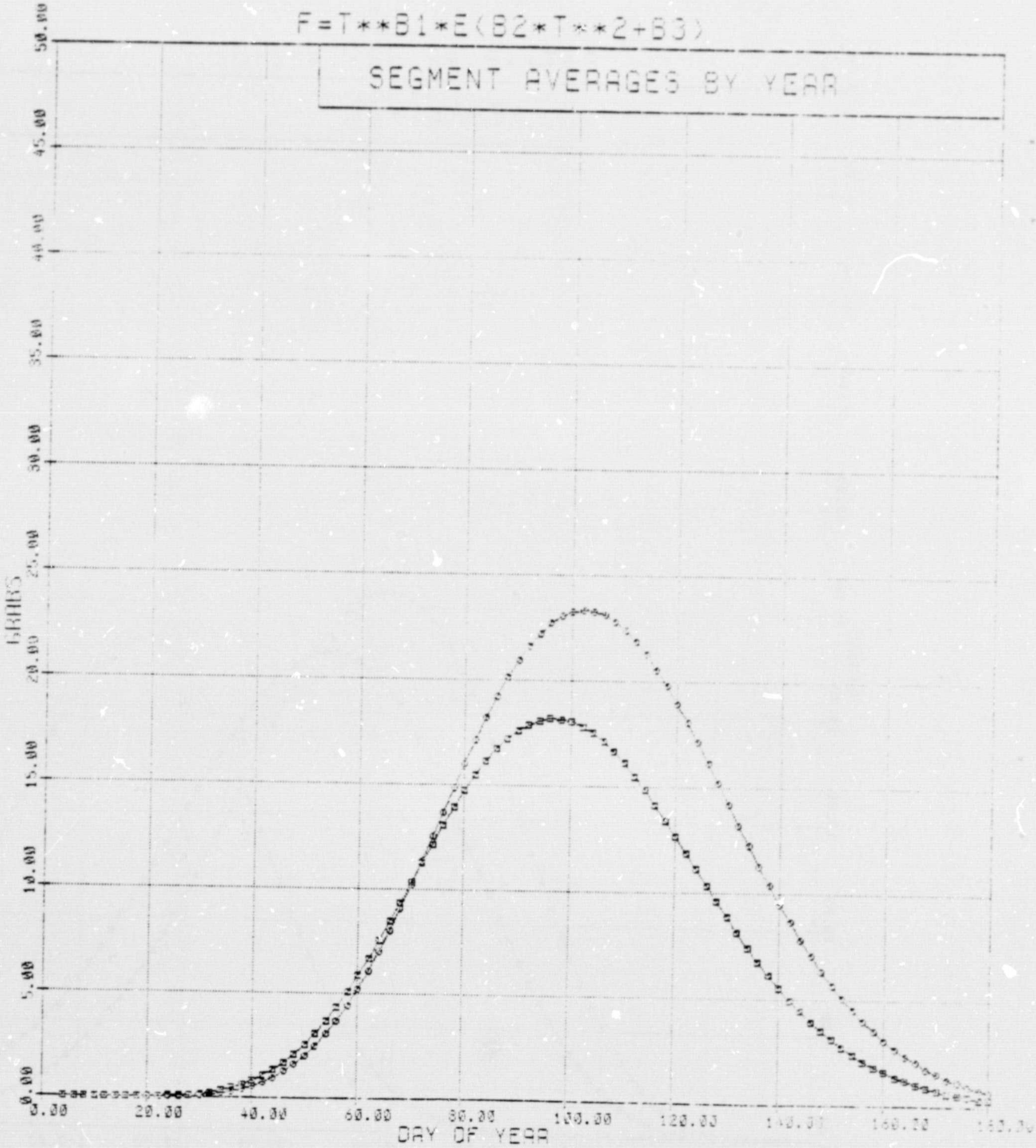


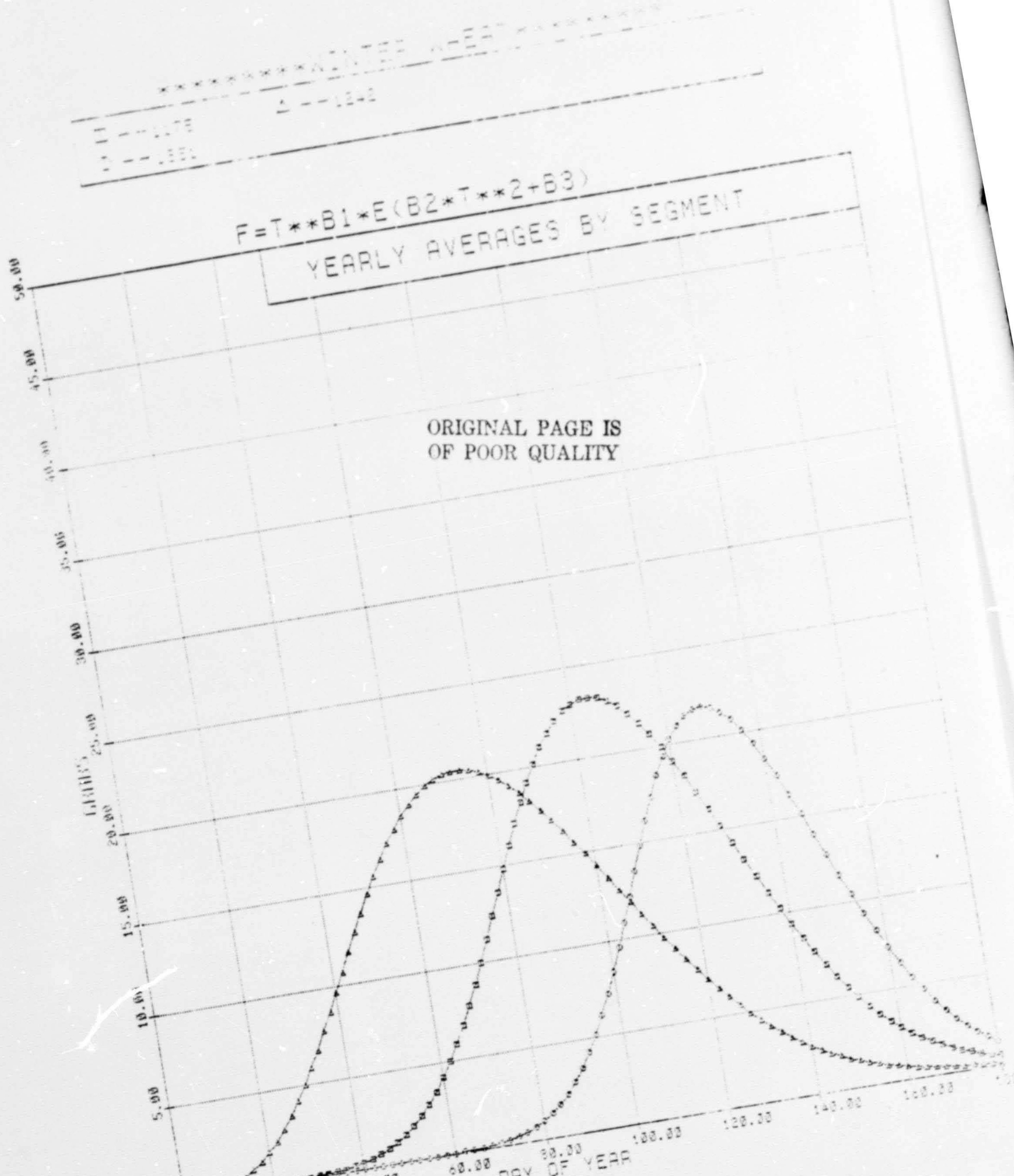

F=T**B1*E(B2*T**2+B3)
YEAR: 1976
GRAMS
DAY OF YEAR
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00

32


F=T**B1*E(B2*T**2+B3)
YEAR: 1977
GRABS
DAY OF YEAR
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00

**********WINTER WHEAT**********





F=T**B1*E(B2*T**2+B3)
YEARLY AVERAGES BY SEGMENT
ORIGINAL PAGE IS
OF POOR QUALITY
DAY OF YEAR

35